Technical Note: Multi-agent Social and Organizational Modeling of the Electric Power and Natural Gas Markets

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Abstract: Complex Adaptive Systems (CAS) can be applied to investigate large-scale socio-cognitive-technical systems. Viewing such systems from a multi-agent social and organizational perspective allows innovative computational policy analysis. ANL has taken such a perspective to produce an integrated model of the electric power and natural gas markets. This model focuses on the organizational interdependencies between these markets. These organizational interdependencies are being strained by fundamental market transformations.

Keywords: Complex adaptive systems (CAS) Agent-based modeling (ABM), Electric power system modeling, Natural gas system modeling, Infrastructure interdependency, Swarm.

I. Introduction

The electric power and natural gas markets are undergoing fundamental transformations. These transformations include major changes in electric generator fuel sources. Electric generators that use natural gas as a fuel source are rapidly gaining market share. Electric generators using natural gas introduce direct interdependency between the electric power and natural gas markets. The interdependencies between the electric power and natural gas markets introduced by these generators can be investigated using the emergent behavior of CAS model agents.

II. Infrastructures

The CAS model agents within the Spot Market Agent Research Tool Version 2.0 Plus Natural Gas (SMART II+) allow investigation of the interdependencies between the electric power and natural gas markets. SMART II+ is a Swarm-based [1] extension to SMART II, the SwarmFest 2000 Best Presentation winner. SMART II itself builds on several other models [2-3]. SMART II+ includes an integrated set of agents and interconnections representing each of the following:

- The electric power marketing and transmission infrastructure.
- The natural gas marketing and distribution infrastructure.
- The interconnections between the two infrastructures in the form of natural gas fired electric generators.

Both SMART II+ infrastructures include many features:

- Two different kinds of agents, producers and consumers, represent the market participants.
- Interconnections represent transmission or distribution systems with capacities on each line or pipe and complex routing.
- Important economic issues are considered such as investment capital, demand growth for successful consumers, new generation capacity for profitable producers, and bankruptcy for noncompetitive organizations.
- Components can be disabled in real time to simulate failures.

The electric power infrastructure includes the added feature of natural gas fired electric generators. These generators buy fuel from the natural gas market. The resulting electricity is then sold in the electric power market.

III. Producer Agents

Producers determine their production level based on the potential profit to be made. Each producer has investment capital that is increased by profits and reduced by losses. If a producer reaches a predetermined level of investment capital it can purchase additional production capacity in the form of new electric generators or new natural gas sources. New producers are similar to their owner and can connect to the distribution network in either the same location or a new one. Producers that run out of investment capital go bankrupt and no longer participate in the market. Producers choose whether or not to sell energy based on either their cost curves or natural gas prices. Standard producers derive their costs and capacities from cost curves with maximum generation limits as shown in Figure 1.
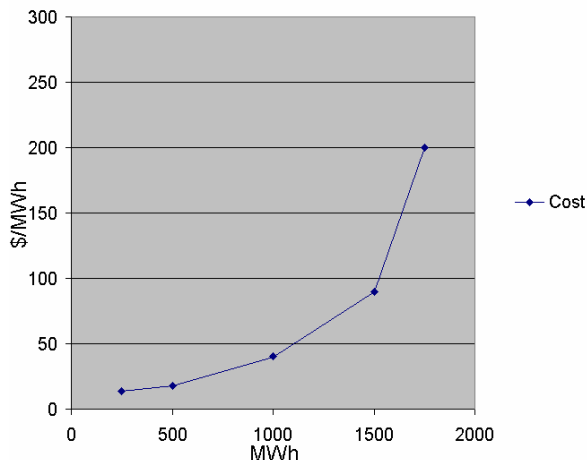

Figure 1: An example producer cost curve

Natural gas fired electric generators derive their costs and capacities from the natural gas market. These generators are consumers in the natural gas marketplace. Their costs are

based on the price they pay for natural gas. Their capacities are based on both the amount of natural gas they can purchase and their design limits.

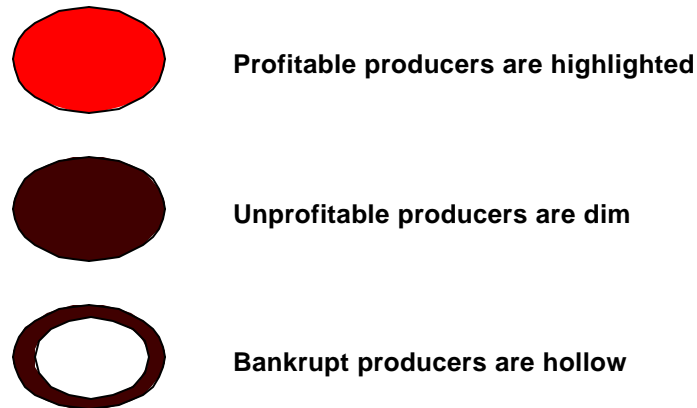Current profit levels determine producer appearance as shown in Figure 2.

Profitable producers are highlighted

Unprofitable producers are dim

Bankrupt producers are hollow

Figure 2: Producer Appearance

IV. Consumer Agents

Consumers buy energy for their own use. Businesses buy fixed amounts of energy to remain in business. Populations buy fixed amounts of energy to live their lives. Natural gas fired electric generators buy natural gas to produce salable electric power. Each consumer has investment capital that is increased by profits and reduced by losses. If a consumer reaches a predetermined level of investment capital it can grow in the form of new consumers. Consumers that run out of investment capital go bankrupt and no longer participate in the market.

Investment capitol represents several things. For industrial users it is their total financial capitol. For individuals it is the employment and personal opportunities that keep them in an area or encourage them to leave

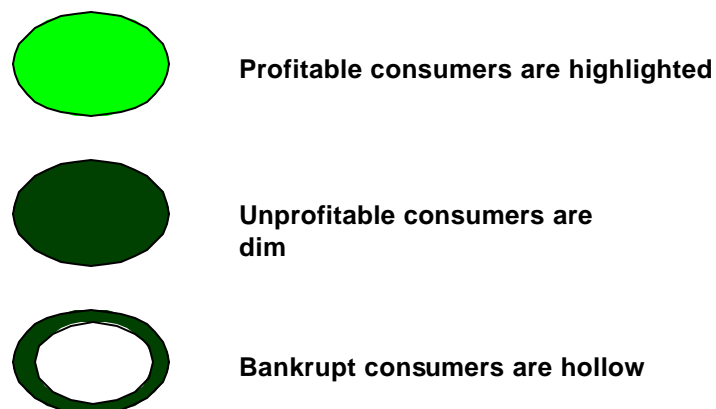Current profit levels determine consumer appearance as shown in Figure 3.

Profitable consumers are highlighted

Unprofitable consumers are dim

Bankrupt consumers are hollow

Figure 3: Consumer Appearance

Interconnections represent transmission lines or distribution pipes each with an individual capacity limit. Individual capacity limits vary by interconnection type. Central transmission lines or main distribution pipes have high capacity limits and are drawn with thick marks. Outlying transmission lines or secondary distribution pipes have moderate capacity limits and are drawn with medium marks. Feeder lines or pipes have low capacity limits and are drawn with thin marks. Interconnection color represents contents and usage as shown in Figure 4.
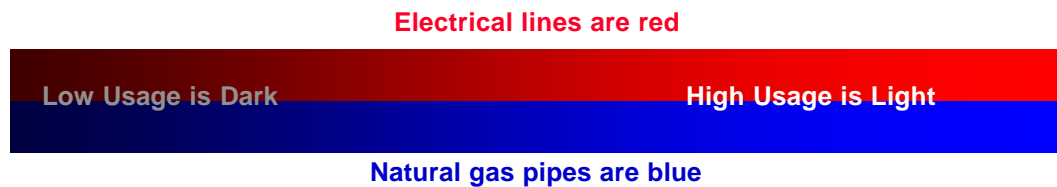

Figure 4: Interconnection Appearance

VI. Market Indicators

The key SMART II+ market indicators are market prices, unserved energy and natural gas fired electrical generator market share. All key SMART II+ indicators are represented by graphs updated in real time.

Market price is the per unit purchase price of the given energy resource. Electric power prices are given in tenths of a cent per kilowatt-hour (Mills/KWh). Natural gas prices are given in dollars per thousand cubic feet ($/1,000 cubic feet). The SMART II+ price graphs are shown in Figure 5.
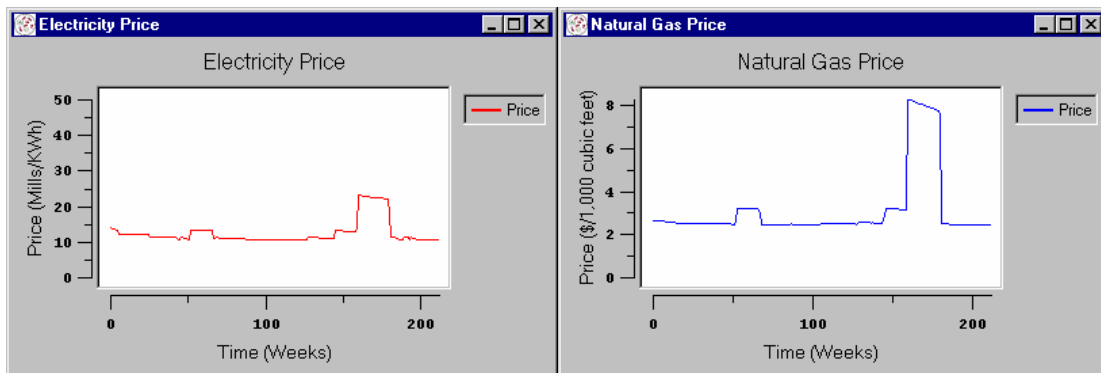

Figure 5: Price Graphs

Unserved energy (UE) is the energy demand that was not met by the market. UE represents a form of market failure. UE is given as a percentage of total energy demand. The SMART II+ UE graph is shown in Figure 6.

Natural gas fired electric generator market share (NG Generator MS) is a measure of the electric generation capacity that is supplied by natural gas units. NG Generator MS is key

to infrastructure interdependency. NG Generator MS is given as a percentage of total capacity. The SMART II+ NG Generator MS graph is shown in Figure 6.
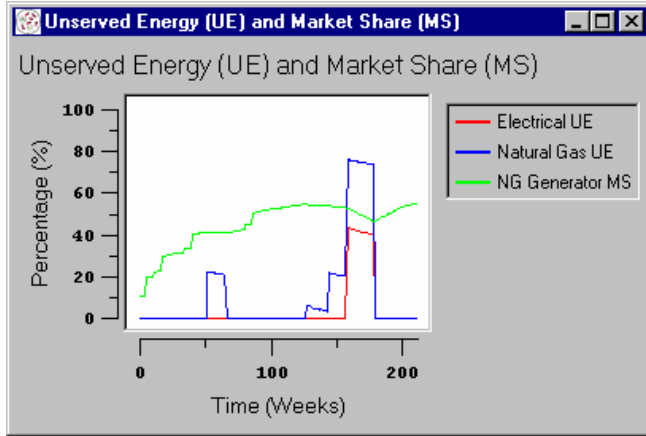

Figure 6: UE and NG Generator MS Graph

VII. Example Network

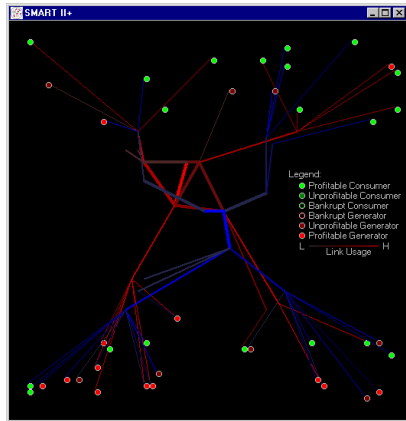An example SMART II+ network is shown in Figure 7.

Figure 7: Example SMART II+ Network

VIII. Conclusions

The emergent behavior of SMART II+ agents allows investigation of the interdependencies between the electric power and natural gas markets. SMART II+ emergent behavior indicates:

- Natural gas fired electrical generators are highly competitive, which causes their market share to rapidly rise.
- Rising natural gas fired electrical generator market share radically increases market interdependence.

- Increasing market interdependence pits the electric power and natural gas markets against one another during simultaneous failures since both markets are fighting for the same underlying resource, natural gas.

Natural gas market share is rapidly rising in the current market place. This fact leads to the conclusion that emergency natural gas purchases by electrical generators need to be carefully monitored to prevent electrical failures from spreading to the natural gas infrastructure.

Developing the initial capability to create CAS models requires substantial organizational investment as demonstrated by the SMART II+ effort. Once this initial investment has been made models can be created that allow innovative computational policy analysis ANL has made this investment by creating and applying SMART II+.

IX. Acknowledgement

X. References

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[2] VanKuiken, J.C., T.D. Veselka, K.A. Guziel, D.W. Blodgett, S. Hamilton, J.A. Kavicky, V.S. Koritarov, M.J. North, A.A. Novickas, K.R. Paprockas, E.C. Portante, and D.L. Willing, APEX User's Guide (Argonne Production, Expansion, and Exchange Model for Electrical Systems) Version 3.0, ANL/DIS/TM-21, Argonne National Laboratory, Argonne, Ill., 485 pages (November 1994).

[3] Veselka, T.D., E.C. Portante, V.S. Koritarov, S. Hamilton, J.C. VanKuiken, K.R. Paprockas, M.J. North, J.A. Kavicky, K.A. Guziel, L.A. Poch, S. Folga, M.M. Tompkins, and A.A. Novickas, Impacts of Western Area Power Administration's Power Marketing Alternatives on Electric Utility Systems, ANL/DIS/TM-10, Argonne National Laboratory, Argonne, Ill., 216 pages (January 1994).